# Archives

## April

Vol. 6 No. 2 (2025)

**Vol.** 6 No. 2 This results from All Accepted manuscripts being pre-published provisionally in "**Articles In Future Issue ITSDI Journal 2025**". This means that this pre-edition article is awaiting official publication in the next issue.


## October

Vol. 6 No. 1 (2024)

**Vol.** 6 No. 1 This results from All Accepted manuscripts being pre-published provisionally in "**Articles In Future Issue ITSDI Journal 2024**". This means that this pre-edition article is awaiting official publication in the next issue.

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## ARTICLES

**IAIC Transactions on Sustainable Digital Innovation (ITSDI)**
Vol. 6, No. 2, April 2025, pp. 150∼163
E-ISSN: 2715-0461 P-ISSN: 2686-6285, DOI:10.34306 

# House of Risk Approach in Determining Delay Risk Factors

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**Article Info**

***Article history:***

Submission January 08, 2025
Revised February 28, 2025
Accepted March 10, 2025
Published March 20, 2025

***Keywords:***

Risk of Delay
House of Risk
House of Delay
Proton Bean Building

**ABSTRACT**

Delays in project completion can lead to significant financial losses, reduced contractor performance, and decreased operational efficiency. This study analyzes the delay factors in the Proton Beam Building construction project at RSPAD Gatot Soebroto, identifying the primary causes and proposing targeted mitigation strategies. A mixed-method approach, combining qualitative interviews and quantitative surveys with key project stakeholders including planning consultants, construction management teams, contractors, and other involved parties is employed. The analysis utilizes the House of Risk (HOR) method to identify and prioritize delay agents and the House of Delay (HOD) method, supplemented by Forum Group Discussions for comprehensive insights. Key research variables encompass human resources, materials, equipment, contract administration, project planning, field conditions, and stakeholder involvement. The study reveals that the primary causes of delays are inadequate planning, design changes, and a shortage of qualified human resources in construction management and planning consulting. The HOR methodology identifies the top three delay agents: **Planning not in accordance with regulations (A8), Design changes (A6)**, and **Lack of human resources (A4)**. To address these issues, the study proposes mitigation strategies, including the creation of a comprehensive checklist for regulatory compliance during planning, ensuring design alignment with applicable regulations, and developing contingency plans to address potential human resource shortages. These strategies aim to reduce the most significant delay risks, improve project efficiency, and enhance overall project compliance.



DOI: https://doi.org/10.34306/itsdi.v6i2.690


## 1. INTRODUCTION

The implementation of construction projects is often hindered by various challenges that lead to delays, resulting in schedule overruns, financial losses, and failure to meet project objectives. These delays are typically unforeseen and impact both contractors and service users, often causing long-lasting effects on project performance. A substantial body of research has focused on identifying the causes of project delays, particularly within the construction industry. Commonly cited causes include inadequate planning, limited resources, and poor coordination among stakeholders [1, 2]. However, projects involving high technology, such as Proton Beam Technology (PBT) infrastructure, face even greater risks of delay due to the need for integration across multiple specialized fields, including engineering, procurement of high-tech equipment, and adherence to stringent health and safety regulations [3].

Government projects, in particular, frequently encounter additional obstacles such as complex bureaucratic processes, regulatory changes, and a shortage of specialized expertise. Projects involving technological innovations are often further delayed by the limited understanding of new technologies by local workers, which increases the complexity of execution and contributes to inefficiencies [4, 5]. The Proton Beam Building construction at RSPAD Gatot Subroto exemplifies the challenges of such high-tech construction projects. Unlike conventional construction, this project combines advanced medical technology with physical infrastructure, demanding not only sophisticated engineering but also strict adherence to BAPETEN standards for High Design Concrete. Moreover, the involvement of multiple agencies in the licensing process has led to extended project timelines and additional coordination hurdles.

Effective project management requires addressing technical, managerial, and regulatory factors that are critical to project success. Implementing effective risk management strategies is vital for minimizing delays, particularly in projects that demand specialized expertise and advanced technological integration [6, 7]. Communication and coordination among stakeholders are essential to overcome barriers during construction; however, the lack of such coordination between contractors, technical consultants, and equipment suppliers often leads to planning errors, technical issues, and discrepancies between procurement and installation schedules [8]. Furthermore, procurement challenges especially those related to complex import processes and licensing requirements frequently delay projects involving high-tech components [9].

Various methods, such as path analysis, mean and ranking techniques, and the relative importance index, have been used to identify delay causes and prioritize them [10, 11]. While these approaches provide valuable insights, they tend to focus primarily on identifying and correlating delay factors without offering actionable solutions [12, 13]. Effective delay management goes beyond identifying causes; it requires a structured approach that leads to practical mitigation strategies [14]. The Borda method, for example, has been utilized to prioritize delay factors based on their potential impact [15]. Risk analysis methods, such as the Probability-Impact Matrix, integrated with PMBOK standards, are commonly applied to evaluate risks, yet these often fall short in offering concrete solutions to mitigate delay factors effectively [16].

One integrated approach that has shown promise in minimizing project delays is the House of Risk (HOR) methodology [17]. The HOR method combines the principles of Failure Mode and Effect Analysis (FMEA) with the House of Quality (HOQ) model, enabling the identification of risks and the development of specific, effective mitigation actions for each identified delay factor [18]. The HOR methodology has been successfully applied in various industries, including manufacturing, where it has demonstrated considerable success in minimizing risks and improving project outcomes [19].

Despite comprehensive planning efforts, the construction of the Proton Beam Building at RSPAD Gatot Subroto has faced significant delays due to disputes and conflicts during the implementation phase [20]. These ongoing issues underscore the need for a systematic, analytical approach to identify delay factors and mitigate their impact on the project timeline [21]. This study aims to analyze the causes of delays in the Proton Beam Building construction, explore the associated risks, and propose practical strategies to mitigate these delays effectively.

Specifically, the study will focus on identifying the primary delay factors in the Proton Beam Building construction project and propose mitigation strategies using the House of Risk methodology [22]. The key objectives of this research are: (i) to analyze delay events, (ii) to identify agents responsible for the delays, and (iii) to develop actionable delay risk mitigation strategies [23]. By adopting the HOR methodology, this research aims to provide valuable insights into improving risk management practices in high-tech construction projects and contributing to better project outcomes.

## 2. MATERIALS AND METHODS

### 2.1. Research Design

This research adopts a case study approach to analyze the delay factors in the Proton Beam Building construction project at RSPAD Gatot Subroto, Jakarta. The primary method used is the House of Risk (HOR), which integrates the principles of Failure Mode and Effect Analysis (FMEA) with the House of Quality (HOQ) model. The HOR method is employed to identify risk agents that contribute to project delays and to propose targeted mitigation strategies. The study combines both **qualitative** and **quantitative approaches** for data collection and analysis.

- Qualitative data are gathered through semi-structured interviews with stakeholders involved in the project, including project owners, contractors, and consultants. These interviews are designed to gather insights into potential delay events, their causes, and stakeholders perceptions of the impact of these delays on project timelines.

- Quantitative data are collected through surveys distributed to a broader group of stakeholders, allowing for the assessment of the frequency and severity of delay events.

The combination of these methods ensures a robust approach to understanding delay risks and how to mitigate them effectively.

Figure 1. Location of study

Figure 1, labeled Location of study, shows the case study site that serves as the research object related to delay risks in construction projects, particularly in bridge construction. The image depicts a building situated in a densely populated urban environment, which is likely an institutional facility or a project site relevant to the context of this study [24]. This location plays an important role in the data collection process, including direct observation, interviews, and surveys [25]. The presence of this image helps readers understand the geographical and physical context of the study and reinforces the validity of the analysis of delay-causing variables that have been previously identified, such as human resources, materials, equipment, contract administration, project planning, field conditions, and stakeholder involvement [26].

### 2.2. Variables

The initial variables used in this study are factors related to the risk of delay in construction projects [15]. These factors are compiled based on literature studies and have been confirmed by professional practitioners to ensure that these factors are valid and often occur in bridge construction projects [27]. The initial variables identified include: Human resources, Materials, Equipment, Contract administration, Project planning, Field conditions, Stakeholder involvement. Forty-seven initial variables have been compiled from the literature and will be further validated through interviews and surveys. These variables are crucial in identifying specific delay agents and understanding their impact on project performance. The initial variables used in this study are factors related to the risk of delay in construction projects [28]. These factors are compiled based on literature studies and have been confirmed by professional practitioners to ensure that these factors are valid and often occur in bridge construction projects [29]. The initial variables identified include: Human resources, Materials, Equipment, Contract administration, Project planning, Field conditions, Stakeholder involvement. Forty-seven initial variables have been compiled from the literature and will be further validated through interviews and surveys. These variables are crucial in identifying specific delay agents and understanding their impact on project performance [30].

### 2.3. Data Collection

Data collection was conducted using interview techniques and distributing questionnaires to predetermined respondents, namely professional practitioners [31]. Respondents were asked to provide an assessment of severity, occurrence, relationship or relation between events and causes of delays, relationship or relation between causes of delays and mitigation actions, and the level of difficulty in making mitigation proposals regarding problems that result in delays in project completion [32].

### 2.4. House of Risk (HOR)

House of Risk (HOR) is a relatively new risk investigation method. Its use uses the FMEA (Failure Mode and Error Analysis) principle (rules) to evaluate risk quantitatively combined with the House of Quality (HOQ) model to prioritize risk agents that must be prioritized first, which will then select the action that is considered most appropriate to the existing conditions to minimize the potential risk that arises by the risk agent [33]. Adopting the House of Quality (HOQ) method to select risk agents must be prioritized as a mitigation action. Ranking A is given to each risk agent based on the ARPj value ranking for each j risk agent. Therefore, researchers can prioritize agents with a high potential to cause risk activities if there are various risk agents [34]. This model with 2 (two) distributions is called the House of Risk (HOR), which is a modification of the HOQ model. Data is analyzed descriptively and quantitatively [25]. Descriptive analysis is data processing that presents the results of observations or measurements in clear descriptions [35]. Quantitative analysis using the Failure Mode and Effect Analysis (FMEA) and House of Risk (HOR) methods stages one and two. Data analysis using this method aims to identify, analyze, measure, and mitigate potential risks from observed cases [36]. The Failure Mode and Effect Analysis (FMEA) method is used to identify the severity level, occurrence level, risk event, and risk agent. The severity and occurrence values are also called the aggregate risk potential (ARP) applied to HOR 1. The ARP value is used to determine the priority of risks that need to be handled first. How to obtain the ARP value on HOR 1, following the following formula;

$$ARP_j = O_j \sum_S i_x R_{ij}$$

There are:
ARP = Agregate risk potential
Oj = chance of risk occurring
Si = risk severity level
Rij = correlation value between risk events and risk agents

### 2.5. Research Stages

1. HOR Phase 1 (risk identification)

   - Identify the occurrence of delays (Ei).
   - Assess the severity impact (severity) on a scale of 1 to 5 regarding the severity level (Si).
   - Identify the agent/cause of the delay and assess the probability of occurrence of delays on a scale of 1-6 probability of occurrence assessment (Oj).
   - Determine the relationship between the cause of the delay and the occurrence of delays using a scale of {0, 1, 3, 9} where 0 indicates no correlation, 1 indicates low correlation, 3 means moderate, and 9 means high.
   - Calculate the Aggregate Delay Potential (ADP_j) value, using formula 1 as follows:

   $$ADP_j = O_j \sum_i S_i R_{ij} \quad (1)$$

   - Sort the ADP values from highest to smallest.

   HOR-1 will identify the occurrence of delays to be given preventive action through the distribution of questionnaires and interviews. At this stage, the results of variable confirmation from the project party regarding the risks experienced by the project.

2. Risk Evaluation with Pareto Diagram
   The results obtained from the ADP value ranking will be depicted in a Pareto diagram using the 80:20 principle to determine the dominant risk source. This dominant risk will be used as a reference for designing delay risk handling, while other risks will be ignored. The stages are as follows:

   - Pareto calculations can be done with the following formula:

   $$Pareto = \frac{ADP_j}{ADP_{\text{Total}}} \times 100\%$$

- Calculating cumulative value
- Making a Pareto diagram

3. HOR Phase 2 (mitigation) HOR-2 analysis is used to prioritize prevention solutions. The following are the stages in HOR-2:

   - Determine the dominant delay factor using a Pareto diagram.
   - Identify practical preventive action proposals according to the delay factor agents.
   - Determine the relationship between each preventive action and each risk agent using a scale of {0, 1, 3, 9} where 0 indicates no correlation, 1 indicates low correlation, 3 means moderate, and 9 means high.
   - Calculate the total effectiveness value *(TEk)*, using formula 2, namely:

$$TEk = \sum_{j} ADP_j E_j k$$

   - Determine the level of difficulty of each mitigation action $D_k$.
   - Calculate the total effectiveness of the level of difficulty ratio $(ETD_k)$ using formula 3, namely:

$$(ETD_k)\textit{TEk}D_k$$

   - Sort the most significant $ETD_k$ values from highest to smallest.

## 3. DISCUSSIONS AND FINDINGS

### 3.1. Delay Incident Identification

The identification of delay incidents in this study was based on the results of field observations and respondent interviews in the Discussion Group Forum [37]. Respondent interviews were beginning to accommodate several inputs from each stakeholder in determining the delay factors in the Proton Beam Building construction process at RSPAD Gatot Subroto [38]. Interviews were conducted with stakeholders involved in the construction implementation that researchers considered to have experience in the field of construction so that they could represent stakeholder needs as input for delay factors to be overcome. The respondents in question were project owners, contractors, planning consultants, and supervisory consultants. Respondents selected at the interview stage included:

1. Owner / Project Owner 1 (one) person, the resource person understands the process and sequence of events in the field so that they can find out and validate the events and agents of delays that occurred in the construction process of the Proton Beam building at RSPAD Gatot Subroto.
2. Construction service providers (contractors) 8 (eight) people, the resource persons interviewed, were contractors who participated in the Proton Beam building construction process at RSPAD Gatot Subroto.
3. The interviewed personnel were the contractor, project manager, or project implementer.
4. Construction consultant service provider 1 (one) person, the interviewee, was the team leader or expert consultant supervisor.
5. Planning consultant service provider 1 (one) person, the interviewee was the team leader or expert consultant planning

After conducting direct interviews, the researcher meticulously re-recorded the interview results, which were then submitted for verification by the data owner (the owner). This verification step was implemented to ensure that the researcher's interpretation accurately reflected the intentions and perspectives of the interviewees [39]. By engaging in this process, the researcher ensured that any potential biases or misinterpretations were addressed, providing a clearer and more reliable set of data. Additionally, the researcher interviewed a total of 11 carefully selected respondents, and upon analyzing their responses, several recurring themes, opinions, and suggestions emerged. These similarities allowed the researcher to categorize and group the events and agents associated with delays in the construction process [40]. These delays were specifically identified during interviews with key stakeholders involved in the construction of the Proton Beam building at RSPAD Gatot Subroto. Each stakeholder contributed their assessment of the severity of each identified delay event, which was validated and cross-checked by the owner and the project consultant. The results of this comprehensive respondent survey, reflecting the varied assessments from different stakeholders, can be found in Table 1. These insights provide an invaluable contribution to understanding the underlying causes of delays in the project and offer a clearer picture of the risks involved in large-scale construction projects. The data gathered will inform more effective strategies for mitigating delays in future projects [41].

| Kode | Delay Event | Severity |
|---|---|---|
| E1 | Work delay due to owner error | 4 |
| E2 | Work delay due to Construction Management error | 4 |
| E3 | Contractor work handover delay | 3 |
| E4 | Work delay due to contractor/subcontractor error | 2 |
| E5 | Work delay due to administrative process | 3 |

Table 1. Delay Identification and Delay Impact Assessment Result

From Table 1, it is known that 2 Delay events have a value of 4, which means that they have a profound impact and significantly affect the completion of the project according to validation during the interview, 2 delay events with a value of 3 mean that they have a moderate impact and 1 delay event with a value of 2 which has a slight impact because it is in the construction of the Proton Beam building at RSPAD Gatot Subroto. This impact value will be used in the calculation of Aggregate Delay Potential (ADP), namely to determine the most influential agent/cause of delay based on the calculation.

### 3.1.1. Identification of Agents/Causes of Delay

Identification of causes/agents of delay comes from interviews conducted by researchers with stakeholders and data available on the Proton Beam building construction project at RSPAD Gatot Subroto. Starting from the delay event, researchers traced through interviews and data what the agents of delay were in each delay event. The results of the discussion in the interview can be seen in Table 2.

Table 2. Delay Agent Identification

| No | Delay Event | Delay Agent |
|---|---|---|
| 1 | Work delays due to administrative processes | Occurrence of scope of work collision between contractors, Contractor files do not match, Additional scope of work, Differences in work implementation time and scope of work between contractors and other service providers, Shop drawing has a change. |
| 2 | Delays in work due to Construction Management errors | Materials imported from abroad, Scope of work not included in BQ and RAB, Length of Construction Management approval process. |
| 3 | Delays in work due to contractor/subcontractor errors | Lack of human resources, There are conflicts and misunderstandings, Initial contract surveys on contractors do not match with what is being done, There is a collision of work scopes between contractors, Coordination with the owner, There is a renegotiation of new prices and volumes, Contractor files are incomplete. |

| No | Delay Event | Delay Agent |
|---|---|---|
| 4 | Delays in work due to owner error | There are differences in soil tests, Shop drawing has a change, Additional scope of work, Differences in directorates in project implementation, Changes in licensing regulations. |
| 5 | Delay in handover of contractor work | Shop drawing has a change<br>Lack of human resources<br>There are conflicts and misunderstandings<br>Initial contract surveys on contractors do not match with what is being done<br>There is a collision of work scopes between contractors<br>Coordination with the owner<br>There is a renegotiation of new prices and volumes<br>Immature planning<br>There is an addition to the scope of work<br>Terjadinya perbedaan soil test<br>There is a difference in soil tests<br>Planning does not comply with regulations. |

The respondents assessment of the potential delay agents was meticulously carried out through a series of structured interviews with contractors who have firsthand experience with the project's execution and challenges [42]. These interviews were designed to capture a comprehensive understanding of the factors that could potentially cause delays, ranging from logistical issues to human resource constraints [43]. After collecting these insights, the results were subjected to a thorough validation process, where the owner, planning consultants, and construction management team reviewed the findings to ensure they accurately represented the broader scope of potential delays across various phases of the project [44]. This collaborative approach helped to refine the assessment, aligning it with both theoretical knowledge and practical, on-the-ground experience. The final outcomes of this assessment, which reflect the likelihood and severity of each identified delay agent, can be seen in Table 3. The table provides a clear and systematic overview of the factors that pose the greatest risk to the project timeline, offering stakeholders an actionable framework to address and mitigate these risks throughout the duration of the project [45].

Table 3. Respondents Assessment of Agent Delay Probability

| Kode | Delay Agent | Occurrence |
|---|---|---|
| A1 | Differences in the time period for the implementation of work and the scope of work between contractors and other service providers | 4 |
| A2 | Shop drawing and specification have changes | 3 |
| A3 | Materials are imported from abroad | 4 |
| A4 | Competence and lack of human resources in Construction Management and Planning Consultants | 3 |
| A5 | Additional scope of work | 4 |
| A6 | Design changes | 4 |
| A7 | Scope of work not included in BQ and RAB | 3 |
| A8 | Planning does not comply with regulations | 5 |
| A9 | Changes in licensing regulations | 2 |
| A10 | Differences in soil tests | 3 |
| A11 | Length of Construction Management approval process | 3 |
| A12 | Differences in directorates in project implementation | 2 |

The probability value will be used to calculate the Aggregate Delay Potential (ADP) and determine the most influential agent/cause of delay based on the calculation.

### 3.2. Delay Evaluation

Five distinct delay events have been identified during the study, each contributing to the overall project delay. In the previous phase of the analysis, twelve delay agents or causes were recognized, each playing a significant role in the disruption of the project timeline [46]. It is important to note that the relationship between delay agents and delay events is not one-to-one; a single delay agent can lead to one or more delay events, while conversely, one delay event can be caused by multiple delay agents [47]. The ranking order of these delay agents, from the highest to the lowest impact, can be found in Table 4, providing a clear understanding of which factors are most critical in influencing project delays [48]. This ranking serves as a valuable tool for project managers and stakeholders to prioritize mitigation strategies and better allocate resources to address the most significant sources of delay in the construction process [49].

| Kode | Delay Agent | Ranking |
|---|---|---|
| A8 | Planning does not comply with regulations | 1 |
| A6 | Design changes | 2 |
| A4 | Competence and lack of human resources in Construction Management and Planning Consultants | 3 |
| A9 | Changes in licensing regulations | 4 |
| A10 | Differences in soil tests | 5 |
| A2 | Shop drawing and specification have changes | 6 |
| A5 | Additional scope of work | 7 |
| A1 | Differences in the time period for the implementation of work and the scope of work between contractors and other service providers | 8 |
| A12 | Differences in directorates in project implementation | 9 |
| A11 | Length of Construction Management approval process | 10 |
| A7 | Scope of work not included in BQ and RAB | 11 |
| A3 | Materials are imported from abroad | 12 |

Table 4. Delay Agent Ranking

Based on Table 4 above, the top three delay agent rankings have been identified, which highlight the most critical factors affecting project timelines. These top-ranked agents were selected due to their significant impact on the overall project schedule. To provide a deeper understanding of the risks associated with these delay agents, a detailed explanation of their potential consequences can be found in Figures 2, 3 and 4 below. These figures offer a visual representation of how each delay agent interacts with other factors, providing insights into the severity of their effects and how they contribute to delays in the project execution. By examining these figures, stakeholders can better assess the risks involved and take proactive measures to mitigate them, ensuring smoother project management and timely completion.

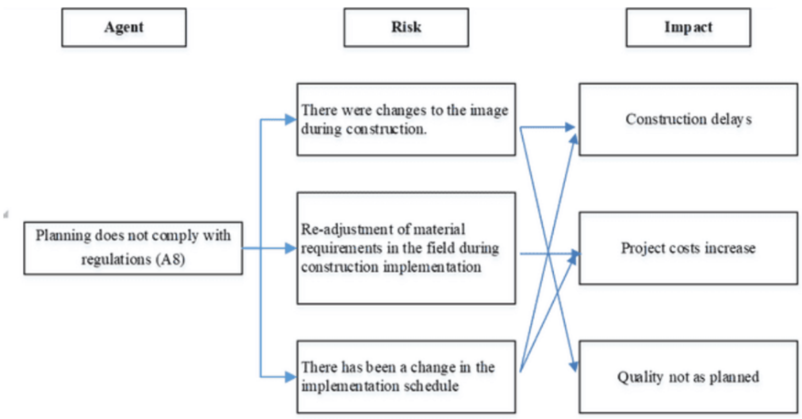


Figure 2. The consequences of planning not in accordance with regulations.S

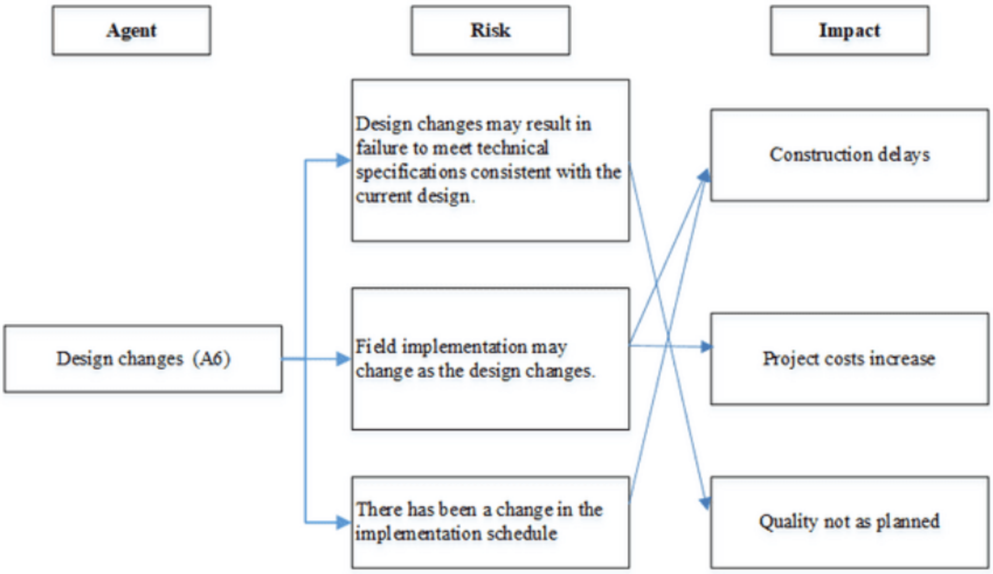


Figure 3. As a result of the design changes

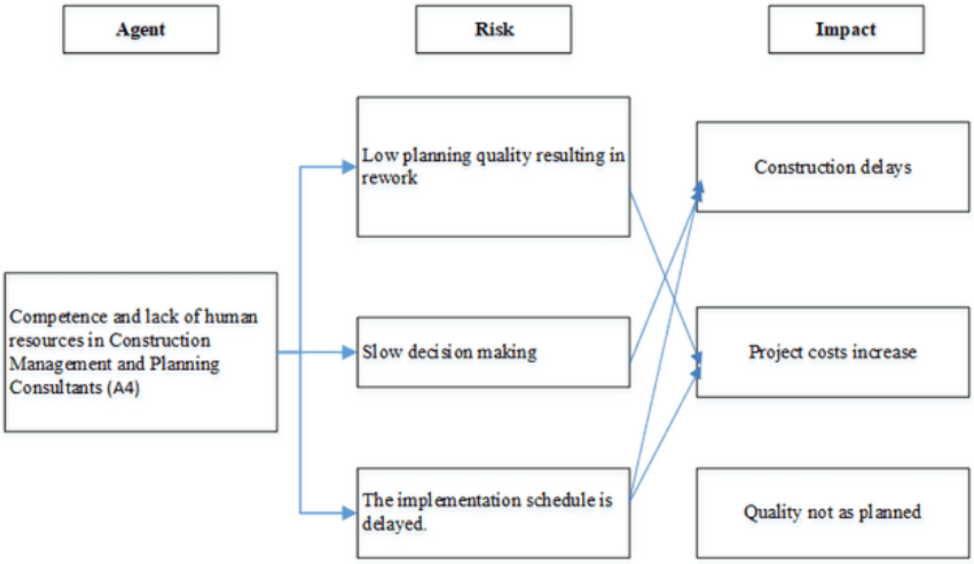


Figure 4. Competence and lack of human resources in Construction Management and Planning Consultants

### 3.3. Mitigation

In order to achieve the project target, the mitigation actions of each delay agent can be identified, which can be seen in Figure 5, namely:

1. Planning that does not comply with regulations can be overcome by creating a comprehensive checklist of all relevant regulatory requirements and used during the planning process
2. Design changes can be overcome by ensuring that the initial design has been aligned with applicable regulations
3. Competence and lack of human resources in Construction Management and Planning Consultants can be overcome by creating a contingency plan to overcome potential human resource shortages.

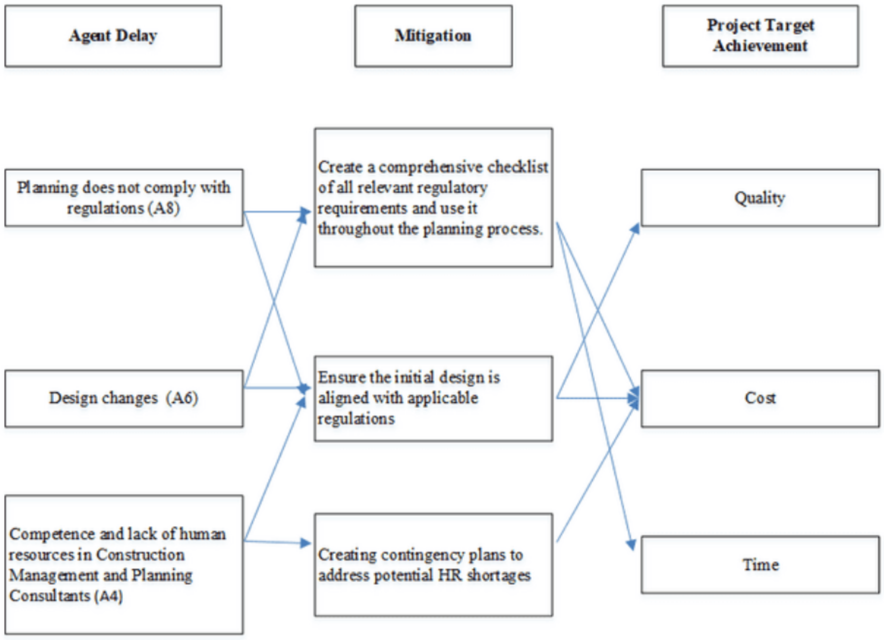


Figure 5. HOR 2 Result

Based on the results of the research that has been conducted with reference to the theory, the construction project of the Proton Beam Building at RSPAD Gatot Subroto, when viewed from the cause, tends to be an excusable compensable delay, namely a delay caused by the owner so that the contractor is entitled to an extension of time and a claim for the delay. The situation that occurred due to the direct appointment of the planning consultant by the owner and the incompetent construction management conditions resulted in the implementation of construction by the contractor being hampered so that several conflicts occurred that caused delays in the completion of the Proton Beam Building construction project at RSPAD Gatot Subroto. The type of delay that occurred in the construction project of the Proton Beam Building at RSPAD Gatot Subroto is included in the concurrent delay type, meaning a delay caused by the owner and other parties so that the contractor is entitled to an extension of time and compensation for the cost of the extension of time. The conditions that occur will have an impact on punctuality, quality and cost, so to overcome the delay, this study adopts the House of Risk method in analyzing delays and finding appropriate mitigation actions. Based on this analysis, the results obtained were the highest causes of delay, namely planning that is not in accordance with regulations, changes in design and competence, and lack of human resources in construction management and planning consultants (HOR 1). The cause of the delay was then subjected to a further HOR 2 analysis stage to obtain mitigation actions, which include creating a comprehensive checklist of all relevant regulatory requirements used during the planning process, ensuring that the initial design has been aligned with applicable regulations, and creating a contingency plan to address potential HR shortages. In this study, a modification of the house of risk method was carried out to analyze delays by adding mitigation actions based on field conditions during implementation.

## 4. MANAGERIAL IMPLICATIONS

This study highlights key managerial actions to reduce delays in construction projects. First, thorough planning and regulatory compliance are essential. Project managers should use a regulatory checklist during planning to ensure the design meets standards and reduce delays caused by non-compliance.

Additionally, skilled human resources are critical to project success. Managers should focus on training and creating contingency plans to address potential staff shortages, especially in complex projects involving advanced technology.

Lastly, design changes are a major delay factor. Managers should ensure comprehensive design approval before project execution to minimize changes. By applying the House of Risk (HOR) approach, managers can better identify and mitigate risks, leading to improved project efficiency.

## 5. CONCLUSION

This study used the House of Risk (HOR) methodology to analyze the delay factors in the Proton Beam Building construction project at RSPAD Gatot Subroto. The analysis identified the main factors contributing to delays: (1) Planning not in accordance with regulations (A8), (2) Design changes and competence issues (A6), and (3) Lack of human resources in construction management and planning consultants (A4). These factors were found to have a significant impact on the project's timeline and were ranked according to their Aggregate Delay Potential (ADP).

The most significant delay agents, as identified in the study, were prioritized for mitigation. Based on the findings, mitigation actions were proposed, including: (1) the development of a comprehensive checklist to ensure compliance with all relevant regulatory requirements during the planning phase, (2) alignment of the initial design with applicable regulations to prevent design changes during later stages, and (3) the creation of contingency plans to address potential shortages in human resources. These strategies aim to minimize the most impactful delays and ensure smoother project execution.

In conclusion, this study highlights the importance of integrating systematic risk management practices, like the HOR method, to not only identify delay factors but also to propose actionable solutions. By implementing these mitigation strategies, construction projects especially those involving high tech infrastructure can significantly reduce the risk of delays, enhance project efficiency, and improve overall outcomes. Future research could explore the application of the HOR methodology in different industries to further refine its effectiveness in delay management.

## 6. DECLARATIONS

### 6.1. About Authors

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### 6.2. Author Contributions

Conceptualization: RK; Methodology: EK, BE and TW; Software: RK and TW; Validation: BE and TW; Formal Analysis: BE and EK; Investigation: EK, BE, and TW; Resources: RK; Data Curation: TW; Writing Original Draft Preparation: RK, EK, BE, and TW; Writing Review and Editing: RK, BE, and TW; Visualization: RK; All authors, RK, EK, BE, and TW, have read and agreed to the published version of the manuscript.

### 6.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

### 6.4. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

### 6.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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**IAIC Transactions on Sustainable Digital Innovation (ITSDI)**
Vol. 6, No. 2, April 2025, pp. 150∼163
E-ISSN: 2715-0461 P-ISSN: 2686-6285, DOI:10.34306 

# House of Risk Approach in Determining Delay Risk Factors

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**Article Info**

***Article history:***

Submission January 08, 2025
Revised February 28, 2025
Accepted March 10, 2025
Published March 20, 2025

***Keywords:***

Risk of Delay
House of Risk
House of Delay
Proton Bean Building

**ABSTRACT**

Delays in project completion can lead to significant financial losses, reduced contractor performance, and decreased operational efficiency. This study analyzes the delay factors in the Proton Beam Building construction project at RSPAD Gatot Soebroto, identifying the primary causes and proposing targeted mitigation strategies. A mixed-method approach, combining qualitative interviews and quantitative surveys with key project stakeholders including planning consultants, construction management teams, contractors, and other involved parties is employed. The analysis utilizes the House of Risk (HOR) method to identify and prioritize delay agents and the House of Delay (HOD) method, supplemented by Forum Group Discussions for comprehensive insights. Key research variables encompass human resources, materials, equipment, contract administration, project planning, field conditions, and stakeholder involvement. The study reveals that the primary causes of delays are inadequate planning, design changes, and a shortage of qualified human resources in construction management and planning consulting. The HOR methodology identifies the top three delay agents: **Planning not in accordance with regulations (A8), Design changes (A6)**, and **Lack of human resources (A4)**. To address these issues, the study proposes mitigation strategies, including the creation of a comprehensive checklist for regulatory compliance during planning, ensuring design alignment with applicable regulations, and developing contingency plans to address potential human resource shortages. These strategies aim to reduce the most significant delay risks, improve project efficiency, and enhance overall project compliance.



DOI: https://doi.org/10.34306/itsdi.v6i2.690


## 1. INTRODUCTION

The implementation of construction projects is often hindered by various challenges that lead to delays, resulting in schedule overruns, financial losses, and failure to meet project objectives. These delays are typically unforeseen and impact both contractors and service users, often causing long-lasting effects on project performance. A substantial body of research has focused on identifying the causes of project delays, particularly within the construction industry. Commonly cited causes include inadequate planning, limited resources, and poor coordination among stakeholders [1, 2]. However, projects involving high technology, such as Proton Beam Technology (PBT) infrastructure, face even greater risks of delay due to the need for integration across multiple specialized fields, including engineering, procurement of high-tech equipment, and adherence to stringent health and safety regulations [3].

Government projects, in particular, frequently encounter additional obstacles such as complex bureaucratic processes, regulatory changes, and a shortage of specialized expertise. Projects involving technological innovations are often further delayed by the limited understanding of new technologies by local workers, which increases the complexity of execution and contributes to inefficiencies [4, 5]. The Proton Beam Building construction at RSPAD Gatot Subroto exemplifies the challenges of such high-tech construction projects. Unlike conventional construction, this project combines advanced medical technology with physical infrastructure, demanding not only sophisticated engineering but also strict adherence to BAPETEN standards for High Design Concrete. Moreover, the involvement of multiple agencies in the licensing process has led to extended project timelines and additional coordination hurdles.

Effective project management requires addressing technical, managerial, and regulatory factors that are critical to project success. Implementing effective risk management strategies is vital for minimizing delays, particularly in projects that demand specialized expertise and advanced technological integration [6, 7]. Communication and coordination among stakeholders are essential to overcome barriers during construction; however, the lack of such coordination between contractors, technical consultants, and equipment suppliers often leads to planning errors, technical issues, and discrepancies between procurement and installation schedules [8]. Furthermore, procurement challenges especially those related to complex import processes and licensing requirements frequently delay projects involving high-tech components [9].

Various methods, such as path analysis, mean and ranking techniques, and the relative importance index, have been used to identify delay causes and prioritize them [10, 11]. While these approaches provide valuable insights, they tend to focus primarily on identifying and correlating delay factors without offering actionable solutions [12, 13]. Effective delay management goes beyond identifying causes; it requires a structured approach that leads to practical mitigation strategies [14]. The Borda method, for example, has been utilized to prioritize delay factors based on their potential impact [15]. Risk analysis methods, such as the Probability-Impact Matrix, integrated with PMBOK standards, are commonly applied to evaluate risks, yet these often fall short in offering concrete solutions to mitigate delay factors effectively [16].

One integrated approach that has shown promise in minimizing project delays is the House of Risk (HOR) methodology [17]. The HOR method combines the principles of Failure Mode and Effect Analysis (FMEA) with the House of Quality (HOQ) model, enabling the identification of risks and the development of specific, effective mitigation actions for each identified delay factor [18]. The HOR methodology has been successfully applied in various industries, including manufacturing, where it has demonstrated considerable success in minimizing risks and improving project outcomes [19].

Despite comprehensive planning efforts, the construction of the Proton Beam Building at RSPAD Gatot Subroto has faced significant delays due to disputes and conflicts during the implementation phase [20]. These ongoing issues underscore the need for a systematic, analytical approach to identify delay factors and mitigate their impact on the project timeline [21]. This study aims to analyze the causes of delays in the Proton Beam Building construction, explore the associated risks, and propose practical strategies to mitigate these delays effectively.

Specifically, the study will focus on identifying the primary delay factors in the Proton Beam Building construction project and propose mitigation strategies using the House of Risk methodology [22]. The key objectives of this research are: (i) to analyze delay events, (ii) to identify agents responsible for the delays, and (iii) to develop actionable delay risk mitigation strategies [23]. By adopting the HOR methodology, this research aims to provide valuable insights into improving risk management practices in high-tech construction projects and contributing to better project outcomes.

## 2. MATERIALS AND METHODS

### 2.1. Research Design

This research adopts a case study approach to analyze the delay factors in the Proton Beam Building construction project at RSPAD Gatot Subroto, Jakarta. The primary method used is the House of Risk (HOR), which integrates the principles of Failure Mode and Effect Analysis (FMEA) with the House of Quality (HOQ) model. The HOR method is employed to identify risk agents that contribute to project delays and to propose targeted mitigation strategies. The study combines both **qualitative** and **quantitative approaches** for data collection and analysis.

- Qualitative data are gathered through semi-structured interviews with stakeholders involved in the project, including project owners, contractors, and consultants. These interviews are designed to gather insights into potential delay events, their causes, and stakeholders perceptions of the impact of these delays on project timelines.

- Quantitative data are collected through surveys distributed to a broader group of stakeholders, allowing for the assessment of the frequency and severity of delay events.

The combination of these methods ensures a robust approach to understanding delay risks and how to mitigate them effectively.

Figure 1. Location of study

Figure 1, labeled Location of study, shows the case study site that serves as the research object related to delay risks in construction projects, particularly in bridge construction. The image depicts a building situated in a densely populated urban environment, which is likely an institutional facility or a project site relevant to the context of this study [24]. This location plays an important role in the data collection process, including direct observation, interviews, and surveys [25]. The presence of this image helps readers understand the geographical and physical context of the study and reinforces the validity of the analysis of delay-causing variables that have been previously identified, such as human resources, materials, equipment, contract administration, project planning, field conditions, and stakeholder involvement [26].

### 2.2. Variables

The initial variables used in this study are factors related to the risk of delay in construction projects [15]. These factors are compiled based on literature studies and have been confirmed by professional practitioners to ensure that these factors are valid and often occur in bridge construction projects [27]. The initial variables identified include: Human resources, Materials, Equipment, Contract administration, Project planning, Field conditions, Stakeholder involvement. Forty-seven initial variables have been compiled from the literature and will be further validated through interviews and surveys. These variables are crucial in identifying specific delay agents and understanding their impact on project performance. The initial variables used in this study are factors related to the risk of delay in construction projects [28]. These factors are compiled based on literature studies and have been confirmed by professional practitioners to ensure that these factors are valid and often occur in bridge construction projects [29]. The initial variables identified include: Human resources, Materials, Equipment, Contract administration, Project planning, Field conditions, Stakeholder involvement. Forty-seven initial variables have been compiled from the literature and will be further validated through interviews and surveys. These variables are crucial in identifying specific delay agents and understanding their impact on project performance [30].

### 2.3. Data Collection

Data collection was conducted using interview techniques and distributing questionnaires to predetermined respondents, namely professional practitioners [31]. Respondents were asked to provide an assessment of severity, occurrence, relationship or relation between events and causes of delays, relationship or relation between causes of delays and mitigation actions, and the level of difficulty in making mitigation proposals regarding problems that result in delays in project completion [32].

### 2.4. House of Risk (HOR)

House of Risk (HOR) is a relatively new risk investigation method. Its use uses the FMEA (Failure Mode and Error Analysis) principle (rules) to evaluate risk quantitatively combined with the House of Quality (HOQ) model to prioritize risk agents that must be prioritized first, which will then select the action that is considered most appropriate to the existing conditions to minimize the potential risk that arises by the risk agent [33]. Adopting the House of Quality (HOQ) method to select risk agents must be prioritized as a mitigation action. Ranking A is given to each risk agent based on the ARPj value ranking for each j risk agent. Therefore, researchers can prioritize agents with a high potential to cause risk activities if there are various risk agents [34]. This model with 2 (two) distributions is called the House of Risk (HOR), which is a modification of the HOQ model. Data is analyzed descriptively and quantitatively [25]. Descriptive analysis is data processing that presents the results of observations or measurements in clear descriptions [35]. Quantitative analysis using the Failure Mode and Effect Analysis (FMEA) and House of Risk (HOR) methods stages one and two. Data analysis using this method aims to identify, analyze, measure, and mitigate potential risks from observed cases [36]. The Failure Mode and Effect Analysis (FMEA) method is used to identify the severity level, occurrence level, risk event, and risk agent. The severity and occurrence values are also called the aggregate risk potential (ARP) applied to HOR 1. The ARP value is used to determine the priority of risks that need to be handled first. How to obtain the ARP value on HOR 1, following the following formula;

$$ARP_j = O_j \sum_S i_x R_{ij}$$

There are:
ARP = Agregate risk potential
Oj = chance of risk occurring
Si = risk severity level
Rij = correlation value between risk events and risk agents

### 2.5. Research Stages

1. HOR Phase 1 (risk identification)

   - Identify the occurrence of delays (Ei).
   - Assess the severity impact (severity) on a scale of 1 to 5 regarding the severity level (Si).
   - Identify the agent/cause of the delay and assess the probability of occurrence of delays on a scale of 1-6 probability of occurrence assessment (Oj).
   - Determine the relationship between the cause of the delay and the occurrence of delays using a scale of $\{0, 1, 3, 9\}$ where 0 indicates no correlation, 1 indicates low correlation, 3 means moderate, and 9 means high.
   - Calculate the Aggregate Delay Potential (ADP_j) value, using formula 1 as follows:

   $$ADP_j = O_j \sum_i S_i R_{ij} \quad (1)$$

   - Sort the ADP values from highest to smallest.

   HOR-1 will identify the occurrence of delays to be given preventive action through the distribution of questionnaires and interviews. At this stage, the results of variable confirmation from the project party regarding the risks experienced by the project.

2. Risk Evaluation with Pareto Diagram
   The results obtained from the ADP value ranking will be depicted in a Pareto diagram using the 80:20 principle to determine the dominant risk source. This dominant risk will be used as a reference for designing delay risk handling, while other risks will be ignored. The stages are as follows:

   - Pareto calculations can be done with the following formula:

   $$Pareto = \frac{ADP_j}{ADP_{\text{Total}}} \times 100\%$$

- Calculating cumulative value
- Making a Pareto diagram

3. HOR Phase 2 (mitigation) HOR-2 analysis is used to prioritize prevention solutions. The following are the stages in HOR-2:

- Determine the dominant delay factor using a Pareto diagram.
- Identify practical preventive action proposals according to the delay factor agents.
- Determine the relationship between each preventive action and each risk agent using a scale of $\{0, 1, 3, 9\}$ where 0 indicates no correlation, 1 indicates low correlation, 3 means moderate, and 9 means high.
- Calculate the total effectiveness value *(TEk)*, using formula 2, namely:

$$TEk = \sum_j ADP_j E_j k$$

- Determine the level of difficulty of each mitigation action $D_k$.
- Calculate the total effectiveness of the level of difficulty ratio $(ETD_k)$ using formula 3, namely:

$$(ETD_k)TEkD_k$$

- Sort the most significant $ETD_k$ values from highest to smallest.

## 3. DISCUSSIONS AND FINDINGS

### 3.1. Delay Incident Identification

The identification of delay incidents in this study was based on the results of field observations and respondent interviews in the Discussion Group Forum [37]. Respondent interviews were beginning to accommodate several inputs from each stakeholder in determining the delay factors in the Proton Beam Building construction process at RSPAD Gatot Subroto [38]. Interviews were conducted with stakeholders involved in the construction implementation that researchers considered to have experience in the field of construction so that they could represent stakeholder needs as input for delay factors to be overcome. The respondents in question were project owners, contractors, planning consultants, and supervisory consultants. Respondents selected at the interview stage included:

1. Owner / Project Owner 1 (one) person, the resource person understands the process and sequence of events in the field so that they can find out and validate the events and agents of delays that occurred in the construction process of the Proton Beam building at RSPAD Gatot Subroto.
2. Construction service providers (contractors) 8 (eight) people, the resource persons interviewed, were contractors who participated in the Proton Beam building construction process at RSPAD Gatot Subroto.
3. The interviewed personnel were the contractor, project manager, or project implementer.
4. Construction consultant service provider 1 (one) person, the interviewee, was the team leader or expert consultant supervisor.
5. Planning consultant service provider 1 (one) person, the interviewee was the team leader or expert consultant planning

After conducting direct interviews, the researcher meticulously re-recorded the interview results, which were then submitted for verification by the data owner (the owner). This verification step was implemented to ensure that the researcher's interpretation accurately reflected the intentions and perspectives of the interviewees [39]. By engaging in this process, the researcher ensured that any potential biases or misinterpretations were addressed, providing a clearer and more reliable set of data. Additionally, the researcher interviewed a total of 11 carefully selected respondents, and upon analyzing their responses, several recurring themes, opinions, and suggestions emerged. These similarities allowed the researcher to categorize and group the events and agents associated with delays in the construction process [40]. These delays were specifically identified during interviews with key stakeholders involved in the construction of the Proton Beam building at RSPAD Gatot Subroto. Each stakeholder contributed their assessment of the severity of each identified delay event, which was validated and cross-checked by the owner and the project consultant. The results of this comprehensive respondent survey, reflecting the varied assessments from different stakeholders, can be found in Table 1. These insights provide an invaluable contribution to understanding the underlying causes of delays in the project and offer a clearer picture of the risks involved in large-scale construction projects. The data gathered will inform more effective strategies for mitigating delays in future projects [41].

| Kode | Delay Event | Severity |
|---|---|---|
| E1 | Work delay due to owner error | 4 |
| E2 | Work delay due to Construction Management error | 4 |
| E3 | Contractor work handover delay | 3 |
| E4 | Work delay due to contractor/subcontractor error | 2 |
| E5 | Work delay due to administrative process | 3 |

Table 1. Delay Identification and Delay Impact Assessment Result

From Table 1, it is known that 2 Delay events have a value of 4, which means that they have a profound impact and significantly affect the completion of the project according to validation during the interview, 2 delay events with a value of 3 mean that they have a moderate impact and 1 delay event with a value of 2 which has a slight impact because it is in the construction of the Proton Beam building at RSPAD Gatot Subroto. This impact value will be used in the calculation of Aggregate Delay Potential (ADP), namely to determine the most influential agent/cause of delay based on the calculation.

**3.1.1. Identification of Agents/Causes of Delay**

Identification of causes/agents of delay comes from interviews conducted by researchers with stakeholders and data available on the Proton Beam building construction project at RSPAD Gatot Subroto. Starting from the delay event, researchers traced through interviews and data what the agents of delay were in each delay event. The results of the discussion in the interview can be seen in Table 2.

Table 2. Delay Agent Identification

| No | Delay Event | Delay Agent |
|---|---|---|
| 1 | Work delays due to administrative processes | Occurrence of scope of work collision between contractors, Contractor files do not match, Additional scope of work, Differences in work implementation time and scope of work between contractors and other service providers, Shop drawing has a change. |
| 2 | Delays in work due to Construction Management errors | Materials imported from abroad, Scope of work not included in BQ and RAB, Length of Construction Management approval process. |
| 3 | Delays in work due to contractor/subcontractor errors | Lack of human resources, There are conflicts and misunderstandings, Initial contract surveys on contractors do not match with what is being done, There is a collision of work scopes between contractors, Coordination with the owner, There is a renegotiation of new prices and volumes, Contractor files are incomplete. |

| No | Delay Event | Delay Agent |
|---|---|---|
| 4 | Delays in work due to owner error | There are differences in soil tests, Shop drawing has a change, Additional scope of work, Differences in directorates in project implementation, Changes in licensing regulations. |
| 5 | Delay in handover of contractor work | Shop drawing has a change<br>Lack of human resources<br>There are conflicts and misunderstandings<br>Initial contract surveys on contractors do not match with what is being done<br>There is a collision of work scopes between contractors<br>Coordination with the owner<br>There is a renegotiation of new prices and volumes<br>Immature planning<br>There is an addition to the scope of work<br>Terjadinya perbedaan soil test<br>There is a difference in soil tests<br>Planning does not comply with regulations. |

The respondents assessment of the potential delay agents was meticulously carried out through a series of structured interviews with contractors who have firsthand experience with the project's execution and challenges [42]. These interviews were designed to capture a comprehensive understanding of the factors that could potentially cause delays, ranging from logistical issues to human resource constraints [43]. After collecting these insights, the results were subjected to a thorough validation process, where the owner, planning consultants, and construction management team reviewed the findings to ensure they accurately represented the broader scope of potential delays across various phases of the project [44]. This collaborative approach helped to refine the assessment, aligning it with both theoretical knowledge and practical, on-the-ground experience. The final outcomes of this assessment, which reflect the likelihood and severity of each identified delay agent, can be seen in Table 3. The table provides a clear and systematic overview of the factors that pose the greatest risk to the project timeline, offering stakeholders an actionable framework to address and mitigate these risks throughout the duration of the project [45].

Table 3. Respondents Assessment of Agent Delay Probability

| Kode | Delay Agent | Occurrence |
|---|---|---|
| A1 | Differences in the time period for the implementation of work and the scope of work between contractors and other service providers | 4 |
| A2 | Shop drawing and specification have changes | 3 |
| A3 | Materials are imported from abroad | 4 |
| A4 | Competence and lack of human resources in Construction Management and Planning Consultants | 3 |
| A5 | Additional scope of work | 4 |
| A6 | Design changes | 4 |
| A7 | Scope of work not included in BQ and RAB | 3 |
| A8 | Planning does not comply with regulations | 5 |
| A9 | Changes in licensing regulations | 2 |
| A10 | Differences in soil tests | 3 |
| A11 | Length of Construction Management approval process | 3 |
| A12 | Differences in directorates in project implementation | 2 |

The probability value will be used to calculate the Aggregate Delay Potential (ADP) and determine the most influential agent/cause of delay based on the calculation.

### 3.2. Delay Evaluation

Five distinct delay events have been identified during the study, each contributing to the overall project delay. In the previous phase of the analysis, twelve delay agents or causes were recognized, each playing a significant role in the disruption of the project timeline [46]. It is important to note that the relationship between delay agents and delay events is not one-to-one; a single delay agent can lead to one or more delay events, while conversely, one delay event can be caused by multiple delay agents [47]. The ranking order of these delay agents, from the highest to the lowest impact, can be found in Table 4, providing a clear understanding of which factors are most critical in influencing project delays [48]. This ranking serves as a valuable tool for project managers and stakeholders to prioritize mitigation strategies and better allocate resources to address the most significant sources of delay in the construction process [49].

| Kode | Delay Agent | Ranking |
|---|---|---|
| A8 | Planning does not comply with regulations | 1 |
| A6 | Design changes | 2 |
| A4 | Competence and lack of human resources in Construction Management and Planning Consultants | 3 |
| A9 | Changes in licensing regulations | 4 |
| A10 | Differences in soil tests | 5 |
| A2 | Shop drawing and specification have changes | 6 |
| A5 | Additional scope of work | 7 |
| A1 | Differences in the time period for the implementation of work and the scope of work between contractors and other service providers | 8 |
| A12 | Differences in directorates in project implementation | 9 |
| A11 | Length of Construction Management approval process | 10 |
| A7 | Scope of work not included in BQ and RAB | 11 |
| A3 | Materials are imported from abroad | 12 |

Table 4. Delay Agent Ranking

Based on Table 4 above, the top three delay agent rankings have been identified, which highlight the most critical factors affecting project timelines. These top-ranked agents were selected due to their significant impact on the overall project schedule. To provide a deeper understanding of the risks associated with these delay agents, a detailed explanation of their potential consequences can be found in Figures 2, 3 and 4 below. These figures offer a visual representation of how each delay agent interacts with other factors, providing insights into the severity of their effects and how they contribute to delays in the project execution. By examining these figures, stakeholders can better assess the risks involved and take proactive measures to mitigate them, ensuring smoother project management and timely completion.

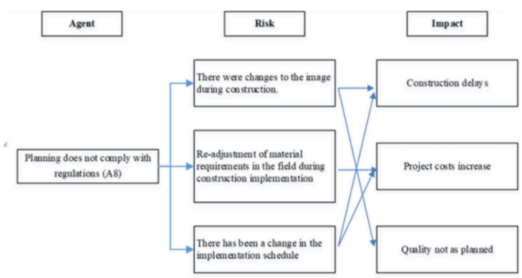


Figure 2. The consequences of planning not in accordance with regulations.S

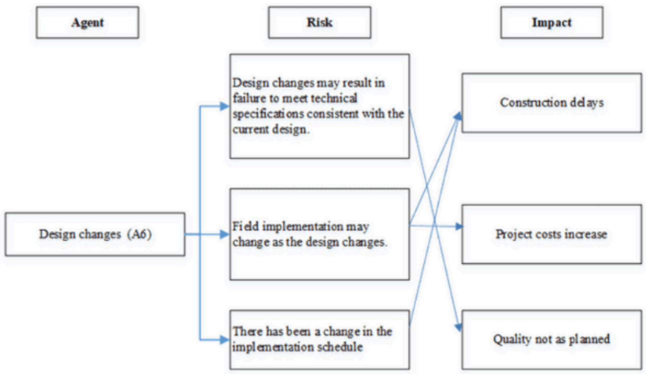


Figure 3. As a result of the design changes

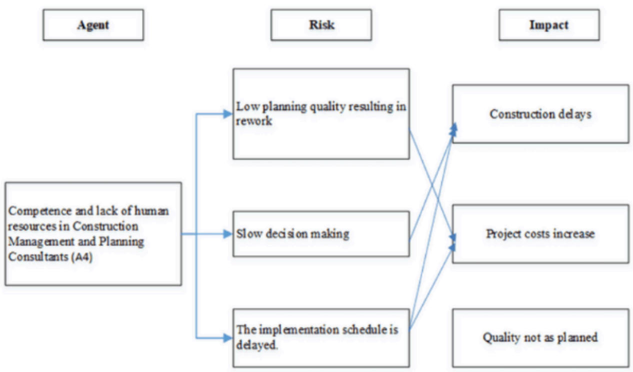


Figure 4. Competence and lack of human resources in Construction Management and Planning Consultants

### 3.3. Mitigation

In order to achieve the project target, the mitigation actions of each delay agent can be identified, which can be seen in Figure 5, namely:

1. Planning that does not comply with regulations can be overcome by creating a comprehensive checklist of all relevant regulatory requirements and used during the planning process
2. Design changes can be overcome by ensuring that the initial design has been aligned with applicable regulations
3. Competence and lack of human resources in Construction Management and Planning Consultants can be overcome by creating a contingency plan to overcome potential human resource shortages.

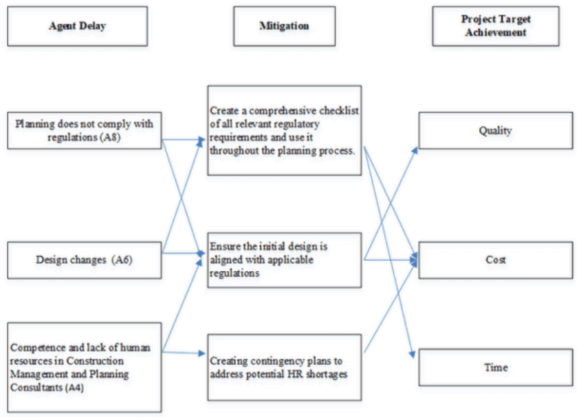


Figure 5. HOR 2 Result

Based on the results of the research that has been conducted with reference to the theory, the construction project of the Proton Beam Building at RSPAD Gatot Subroto, when viewed from the cause, tends to be an excusable compensable delay, namely a delay caused by the owner so that the contractor is entitled to an extension of time and a claim for the delay. The situation that occurred due to the direct appointment of the planning consultant by the owner and the incompetent construction management conditions resulted in the implementation of construction by the contractor being hampered so that several conflicts occurred that caused delays in the completion of the Proton Beam Building construction project at RSPAD Gatot Subroto. The type of delay that occurred in the construction project of the Proton Beam Building at RSPAD Gatot Subroto is included in the concurrent delay type, meaning a delay caused by the owner and other parties so that the contractor is entitled to an extension of time and compensation for the cost of the extension of time. The conditions that occur will have an impact on punctuality, quality and cost, so to overcome the delay, this study adopts the House of Risk method in analyzing delays and finding appropriate mitigation actions. Based on this analysis, the results obtained were the highest causes of delay, namely planning that is not in accordance with regulations, changes in design and competence, and lack of human resources in construction management and planning consultants (HOR 1). The cause of the delay was then subjected to a further HOR 2 analysis stage to obtain mitigation actions, which include creating a comprehensive checklist of all relevant regulatory requirements used during the planning process, ensuring that the initial design has been aligned with applicable regulations, and creating a contingency plan to address potential HR shortages. In this study, a modification of the house of risk method was carried out to analyze delays by adding mitigation actions based on field conditions during implementation.

## 4. MANAGERIAL IMPLICATIONS

This study highlights key managerial actions to reduce delays in construction projects. First, thorough planning and regulatory compliance are essential. Project managers should use a regulatory checklist during planning to ensure the design meets standards and reduce delays caused by non-compliance.

Additionally, skilled human resources are critical to project success. Managers should focus on training and creating contingency plans to address potential staff shortages, especially in complex projects involving advanced technology.

Lastly, design changes are a major delay factor. Managers should ensure comprehensive design approval before project execution to minimize changes. By applying the House of Risk (HOR) approach, managers can better identify and mitigate risks, leading to improved project efficiency.

## 5. CONCLUSION

This study used the House of Risk (HOR) methodology to analyze the delay factors in the Proton Beam Building construction project at RSPAD Gatot Subroto. The analysis identified the main factors contributing to delays: (1) Planning not in accordance with regulations (A8), (2) Design changes and competence issues (A6), and (3) Lack of human resources in construction management and planning consultants (A4). These factors were found to have a significant impact on the project's timeline and were ranked according to their Aggregate Delay Potential (ADP).

The most significant delay agents, as identified in the study, were prioritized for mitigation. Based on the findings, mitigation actions were proposed, including: (1) the development of a comprehensive checklist to ensure compliance with all relevant regulatory requirements during the planning phase, (2) alignment of the initial design with applicable regulations to prevent design changes during later stages, and (3) the creation of contingency plans to address potential shortages in human resources. These strategies aim to minimize the most impactful delays and ensure smoother project execution.

In conclusion, this study highlights the importance of integrating systematic risk management practices, like the HOR method, to not only identify delay factors but also to propose actionable solutions. By implementing these mitigation strategies, construction projects especially those involving high tech infrastructure can significantly reduce the risk of delays, enhance project efficiency, and improve overall outcomes. Future research could explore the application of the HOR methodology in different industries to further refine its effectiveness in delay management.

## 6. DECLARATIONS

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### 6.2. Author Contributions

Conceptualization: RK; Methodology: EK, BE and TW; Software: RK and TW; Validation: BE and TW; Formal Analysis: BE and EK; Investigation: EK, BE, and TW; Resources: RK; Data Curation: TW; Writing Original Draft Preparation: RK, EK, BE, and TW; Writing Review and Editing: RK, BE, and TW; Visualization: RK; All authors, RK, EK, BE, and TW, have read and agreed to the published version of the manuscript.

### 6.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

### 6.4. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

### 6.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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